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AN ATTEMPT TO IMPROVE THE EFFI-
CIENCY OF INCANDESCENT
ELECTRIC LAMPS

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AN ATTEMPT TO IMPROVE THE EFFICIENCY OF
INCANDESCENT ELECTRIC LAMPS

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I N T R O D U C T I O N

Ever since the introduction of lighting by electricity efforts have been directed toward increasing the efficiency of the lamps, that is, decreasing the power required to produce a given amount of illumination. These efforts have resulted in the introduction and development of the Nernst lamp, the metallic filament incandescent lamps such as the tantalum and tungsten lamps, and the metallized carbon filament lamp. It is a well known fact that illumination increases rapidly with increase in temperature of the incandescent body. The original incandescent lamp, employing carbon as a filament, had a very poor efficiency, due to inherent characteristics of carbon. The task of improving the efficiency of these lamps had consequently two methods of procedure open to it. Either the inherent characteristics of carbon must be overcome, or the carbon filament must be replaced by some material which possesses characteristics better suited to high efficiency. The Nernst and metallic filament lamps replace the carbon with other material; the metallized carbon filament lamps partly overcome the inherent characteristics of carbon by a physical change in the carbon. Other methods of overcoming the characteristics of carbon have

been tried, among them that of operating the filament in different gases instead of in vacuum; but none of these have so far been successful.

The following thesis is a report of efforts made to increase the efficiency of incandescent lamps by both methods. The work divides itself into three divisions, as follows:

1. An attempt to overcome the inherent characteristics of the carbon filament lamp by operating the filament in a carbon containing gas.

2. An investigation of the availability of different percentages of the oxides of rare earths for use as glowers in Fernst lamps.

3. An investigation of the availability of cerium nitride for use as a glower when operated in an atmosphere of nitrogen. Nitrides as a class are promising because many of them are known to withstand high temperatures. Cerium nitride is typical of other nitrides and there is thus opened a whole field of investigation relating to the operation of nitrides in nitrogen.

All the ideas are due to Professor Murray C. Beebe of the Electrical Engineering Department, under whose immediate supervision and direction the work was carried out.

Credit is due to the departments of Physics, Chemistry, and Steam Engineering for the use of apparatus and the furnishing of supplies.

TEMPERATURE AND EFFICIENCY

It is not thought necessary to give a complete exposition here of the relation existing between temperature and efficiency. This is too well known to make such a proceeding necessary. It will probably, however, be conducive to a clear understanding of the conditions if the facts are briefly outlined.

Whenever any solid or liquid body is heated, it emits waves of energy. If the temperature of the body is low, the waves are long and useless for illumination purposes. But as the temperature increases, the waves of energy become shorter and of higher frequency, and it is only when the temperature rises sufficiently to add the necessary short wave lengths that any light appears. All the energy put into a body at low temperatures appears as heat and is useless for lighting because the wave lengths are too great to affect the eye, but as the temperature rises, the shorter wave lengths begin to affect the eye as light. The first waves which affect the eye are the red rays, but as the temperature increases, shorter wave lengths continue to appear, more light is given off, and more colors added, until the whole visible spectrum is covered. If the temperature continues to rise, wave lengths occur which

are too short and of too high a frequency to affect the eye. These are known as the ultra violet and actinic rays. Energy, therefore, at any temperature is transformed into heat, light, ultra violet and actinic rays, the distribution depending upon the temperature. The light waves cover but a comparatively small region at any temperature, but as the temperature rises, the wave lengths already present are intensified and more short wave lengths appear. The point of maximum intensity shifts from the region of long wave lengths to that of the shorter wave lengths, and when the point of maximum intensity lies in the middle of the visible spectrum, the highest light efficiency occurs. According to Dr. Steinmetz¹, the temperature for black body radiation at which this maximum efficiency occurs is between 4000 and 5000 degrees Centigrade, and he concludes that light may be given off at this temperature at a specific consumption of from one-quarter to one-half a watt per candle power. Even under this condition, by far the greater percentage of the energy would be transformed into the long heat waves or the ultra violet and actinic rays, all of which are useless for purposes of illumination. Hence the limit of efficiency of incandescent lighting is very low.

There is another important phase of the subject be-

sides that of increased efficiency. As the temperature rises, the variety of wave lengths in the visible spectrum increases and the approximation to white light becomes better. The red light at low temperatures is as undesirable as the intense blue of the arc. In any light-giving body a variety of wave lengths is absolutely necessary and any light which allows a monochromatic wave length to predominate is unsatisfactory. Some substances actually do give preponderance to certain wave lengths at comparatively low temperatures. If this preponderance is not given to objectionable colors such selective radiation, as it is called, may not be a serious disadvantage. The Welsbach mantle, and in a sense, the Fernst lamp are examples of this¹. Both of these emphasize the middle portion of the spectrum, which is the least objectionable to the eye. Selective radiation thus has great possibilities; yet they do not seem as great as those offered by incandescent lighting without selective radiation, for the approximation to sunlight is thereby made better and increases as the efficiency is improved. The present need is a high efficiency incandescent lamp giving a white light. High temperature tends to produce both these ends and hence temperature sets the limits to incandescent lighting.

¹ Proceedings A.I.E.E. 25-761

THE CARBON FILAMENT LAMP

PRACTICAL LIMIT TO TEMPERATURE

It is a well known fact that no substance will maintain its condition for a great length of time at a temperature near its boiling or melting point. If the real cause for this could be determined, it would be a great step toward its elimination. For instance, the carbon filament operates during an economical life period at only about half its actual boiling temperature. Hence, if its efficiency is to be increased by operation at a higher temperature it becomes necessary to know the cause for the present temperature limit.

The deterioration of the carbon filament may be due to electrical effects such as the so-called Edison and Crook's tube effects; to chemical effects such as the action of the enclosed gas on the filament; and to physical effects such as air washing and vaporization. The question as to which of these is the more important cause of deterioration is still a mooted one, but the higher authorities are fairly well agreed that physical effects are the more important. In any event, whether the deterioration be due to electrical, chemical or physical effects, the use of an inert gas in the bulb retards or reduces all of them with the possible exception of air washing.

This latter the authors feel is relatively unimportant as being simply a name used to designate certain minor effects which as yet have not been well understood. Dr. Steinmetz, in a paper before the American Institute of Electrical Engineers¹, illustrates the position of the higher authorities on this subject. His position is very decidedly with those who believe the deterioration to be physical and chemical rather than electrical. While ^{not} it is assumed that the electrical effects are not present it is believed they are small in comparison with the physical causes of deterioration.

The cause generally considered to be most important is vaporization. All solids and liquids evaporate at temperatures far below their melting or boiling points. Carbon has a low vapor tension at low temperatures, but at higher temperatures authorities agree that its vapor tension increases; that at the temperature of incandescence its vapor tension is quite high and that evaporation is relatively rapid². Indications point to this as the chief cause of deterioration. The vaporization of carbon at about 2000 degrees Centigrade is found to be so high that it is not economical to operate it at higher temperatures.

1 Proceedings A. I. E. E. 25-755

2 Comptes Rendus 28 and 29

Beyond this point the wasting away of the filament is so rapid as to reduce the life of the lamp to a very short period. This effect is increased by the fact that the carbon deposits on the bulb, thus obstructing the passage of the light and reducing the practical efficiency. In addition, the filament increases in resistance as the carbon leaves. This reduces the current and lowers the temperature. It is unfortunate that a material so refractory as carbon should have such a comparatively high vapor tension at a temperature so far below the point of instantaneous destruction.

THE NO-VACUUM THEORY.

The theory of vaporization seems to be pretty definitely established, and Professor Anthony, in a paper before the American Institute of Electrical Engineers¹, took pains to prove the truth of the theory with reference to the carbon filament. The logical step then is to reduce vaporization so that higher temperatures may be maintained without excessive evaporation. A well established physical law shows that vaporization is greatly reduced by an atmosphere of a gas under some pressure, and it is upon this law that the no-vacuum theory is based. While the intrinsic vapor tension of the body is not reduced, its rate of vaporization is diminished by the opposing effect of the gas under pressure. If carbon follows the same law at high temperatures, and experiments seem to show that it does, then the presence of a gas under pressure in the lamp bulb must have the desired effect. Early in the development of the lamp this theory was tested by experiments on actual lamps² and so far as vaporization was concerned the experiments pointed conclusively toward the establishment of the theory.

In spite of this theory the carbon incandescent lamp

1 Proceedings A. I. E. E. 11-140

2 American Journal of Science 44-277

is operated under circumstances extremely favorable to rapid vaporization. The fact that carbon withstands as well as it does the temperatures now used under the most adverse circumstances so far as vaporization is concerned, is a good indication of what might be possible under more favorable conditions.

GASES POSSIBLE TO USE IN THE LAMP BULB.

With the vaporization theory pretty well established as explaining the cause for deterioration of the filament, and with the no-vacuum theory opening a possible avenue leading toward the improvement of carbon lamp efficiency, it becomes necessary to investigate the different gases which it might be possible to use in the bulb. It would seem that some of the very inert gases, such as argon, would afford great possibilities, since with such a gas in the bulb vaporization would be reduced, and there would probably be little possibility of chemical combination with the filament. Some of the heavy carbon containing gases, such as carbon tetrabromide (CBr_4) and cyanogen (CN) would also appear to offer possibilities. Some of these gases might afford opportunity for chemical combination with the filament, but if a gas is used which already has its full possible complement of carbon atoms, and is put into the lamp bulb in a pure state and under a pressure such that equilibrium would be established between it and the vapor tension of carbon, there would seem to be no apparent reason why the result should not be satisfactory.

The theory of equilibrium between the gas pressure and the vapor tension supposes that carbon would be va-

porized to a small extent and the gas would be partly broken up, carbon being deposited upon the filament, until an equilibrium was established between the rate of vaporization and the rate of deposition of carbon from the gas. From this it will be seen that the gas used must have the ability to deposit or "flash back" carbon upon the filament. It is upon this basis that the experiments described in this thesis were undertaken.

The idea of operating a carbon filament in an atmosphere of a carbon containing gas, either for the purpose of originally preparing the filament or for the purpose of prolonging its life by the replacement from the gas of the carbon vaporized from the filament, has been the subject of several patents¹. The original preparation of carbon filaments by operating them in carbon containing gases is a process which is well known and widely used at the present time in all the large lamp factories. The idea of normally operating carbon filaments in carbon containing gases for the purpose of prolonging their life or increasing their efficiency, however, has, so far as the authors of this thesis are aware, never been commercially used.

1 U. S. Letters Patent No. 563,329-Frank S. Smith, July 7, 1896
 246,416-Thos. A. Edison, Oct. 16, 1881
 405,170-Hiram S. Maxim, June 11, 1889
 275,613-Thos. A. Edison, Apr. 10, 1883

At the present time investigations are being carried on at the University of Wisconsin which have for their object the determination as to whether or not the use of argon in the bulb of an incandescent lamp will reduce the rate of vaporization. If it should be found that the use of argon will reduce the rate of vaporization, then possibly the use of argon in connection with a carbon containing gas such as cyanogen may produce satisfactory results, argon being used to reduce the rate of vaporization, and cyanogen being used to flash back upon the filament a sufficient amount of carbon to replace the little that would still be vaporized.

EXPERIMENTS AND RESULTS.

In surrounding the filament with a carbon containing gas under pressure, the ideal condition desired was a pressure just sufficient to balance the vaporization. The exact pressure necessary was unknown, but it was believed that if the gas was placed in the bulb under too low a pressure vaporization would take place slowly until equilibrium was established; if placed in the bulb under too much pressure, carbon would be deposited or "flashed" upon the filament until equilibrium was established.

An attempt was first made to use carbon tetrabromide gas in the bulb. The attempt was very rough and was simply for the purpose of determining whether this gas offered possibilities sufficient to justify further and more careful experiments with it. A 50-volt 10-candle power lamp was used for the purpose. In it were placed several crystals of carbon tetrabromide. The lamp was then connected with a vacuum pump of the Fleuss type and the lamp evacuated. When maximum vacuum was obtained, the filament was operated for a few moments at a low red heat to dispel any occluded moisture, after which the crystals of carbon tetrabromide were evaporated by the application of a flame to the outside of the bulb. This occurred very readily under the low pressure. The lamp was then sealed off and

operated at practically double its rated voltage. It operated for fifteen minutes and then burned out. No candle power readings were made, but after the first few minutes the gas in the bulb turned brown as though indicating the presence of free bromine. There was also a reddish white sublimation on the globe. After the lamp burned out, the globe was broken and the filament examined under a microscope. It was found to have on it a heavy black deposit, very tough in its nature, like carbon.

An attempt to ascertain the vapor tension of carbon tetrabromide resulted negatively. A crystal placed in the top of a barometer tube vaporized and produced a pressure of approximately half a centimeter of mercury. A curious and significant point, however, is the fact that when the crystal vaporized in the vacuum over the mercury, it produced on the sides of the tube a black deposit similar to that on the lamp filament and the interior of the globe. This would seem to indicate that the substance decomposes upon evaporation. This being the case it was thought that the use of some other gas might offer greater opportunities.

The use of cyanogen gas was then considered, and in order to determine whether this gave promise of being available, a rough test was made similar to that with the

carbon tetrabromide. A 50-volt lamp was evacuated and filled with cyanogen gas made in a separate chamber by heating mercury cyanide. When tested under double normal voltage this lamp burned for twenty-five minutes. A microscopic examination of the filament showed it to be covered with a hard, lustrous deposit like graphite, and very brittle. A second lamp filled with cyanogen made by heating silver cyanide, operated for twenty minutes under voltage and a half. The inside of this lamp globe became coated with a white sublimate which, at first, covered the entire surface, but which gradually disappeared from the hottest portions and finally gathered in the comparatively cool base. The filament temperature became exceedingly high, appearing to be about the same as that in a 40 watt tungsten lamp. A microscopic examination of the filament showed it to be covered with a hard black deposit like carbon. The filament was very brittle. Tests on the deposit inside the globe showed that it vaporized on application of heat, and dissolved instantly in water. But it apparently did not take up any moisture from the air, although exposed to the atmosphere for several weeks. These tests were made on the supposition that the deposit, might be phosphorus pentoxide which was used to remove the last traces of moisture before sealing the bulb.

As a matter of interest, a lamp fitted with discharge

terminals and tube, as shown in Figure 1, and pumped in the ordinary manner at the factory of one of the large lamp manufacturers, was compared spectroscopically with both hydrogen and cyanogen standards. This comparison showed that the ordinary lamp bulb contains no hydrogen. When compared with the cyanogen spectrum, however, the following was shown:

Item	Lamp Spectrum	Cyanogen Spectrum
1	Not present	Green line
2	Yellow line (pronounced)	Yellow line (pronounced)
3	Not present	Line just to left of yellow
4	Red line (pronounced)	Red line (pronounced)
5	Blue line (pronounced)	Blue line (pronounced)
6	Light Green (pronounced)	Light Green (pronounced)

In view of the pronounced coincidences in items 2, 4, 5, and 6, and of many minor coincidences, it seems safe to conclude that the ordinary lamp bulb contains at least a trace of cyanogen. This is interesting and perhaps important in helping to produce the comparatively long life of carbon lamps, i. e., there may be at the present time some flashing back on to the filament of carbon from the enclosed gases.

In the two lamps tested with cyanogen it was not known whether the gas was pure, nor was the gas pressure

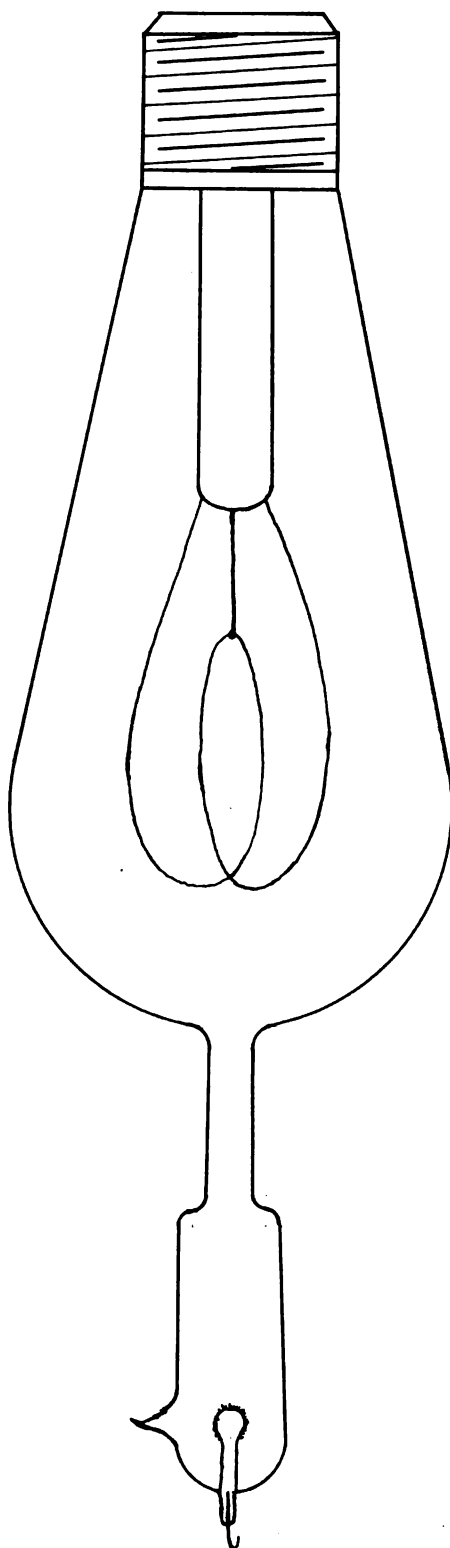


FIGURE 1.

known. The results obtained from these two lamps seemed encouraging and to warrant further investigation. In view of this and of the fact that ordinary lamp bulbs contain a trace of cyanogen, it was decided to make further experiments along this line, endeavoring to use pure cyanogen gas and to determine and regulate the pressure used.

At this point in the work, however, it was found that the valves in the only available vacuum pumps had become so deteriorated that it was impossible to secure the necessary high vacuum. A rush order for new valves was sent to the pump manufacturers in England, but these did not arrive in time to allow further experiments to be made.

PERCENTAGES OF RARE EARTH OXIDES FOR GLOWERS.

HISTORICAL DEVELOPMENT OF GLOWERS.

The peculiar phenomenon of incandescence as a result of the conduction of an electric current through the oxides of various electrolytes, particularly the oxides of the rare earths, has been made the subject of exhaustive research by a host of investigators.

Such substances as lime, magnesia, and kaolin, or white clay, have long been known to possess the power to emit an intense light in the high temperature of the electric arc. It is, however, difficult to say with any degree of accuracy just when it was first found that electrolytes, of which the substances named are a type, when brought to a high temperature by the passage of an electric current, were possessed of the same or greater brilliancy.

Perhaps one of the first men to discover these strong characteristics was La Roux, a Frenchman, who at an early date made experiments using lime and magnesia as conductors in an electric arc¹. Later he patented his

¹ Electric Review, London, February 24, 1899.

idea, including not only the substances mentioned, but a number of substances now known as rare earths.

La Roux's results were in no wise successful, but a few years later Jablockoff brought out his "Kaolin Candle" which consisted of a slab of porcelain used as a conductor of interrupted current at a high potential. Jablockoff's efforts were also unavailing.

Research along these lines was again at a standstill until about 1896 when Doctor Nernst, at the University of Göttingen, produced his lamp. To be brief, this latter attempt to utilize the inherent qualities of the rare earth oxides met with unqualified success.

In his earlier attempts Doctor Nernst's researches were carried on along identical lines with those of his predecessors. But his later work which resulted in the mixtures of the rare oxides was, perhaps, the direct result of a close study and investigation of the findings of Welsbach, of gas mantle fame.

Baron Von Welsbach¹ found that if he mixed thorium with a very small amount of ceria, the resulting mixture was not only stable in a commercial sense but when brought to a state of incandescence gave a spectrum

¹ A. Maissou, *Traité de Chimie Minérale Application du Thorium* Vol. 3 p 867

which was about midway between those of either of the ingredients. Ordinarily thoria possesses no properties coincident with luminous elements or elements capable of incandescence at high temperatures, but ceria taken alone gives off a very intensely brilliant light at high temperatures. The latter's stability is, however, very slight and it volatilizes at those high temperatures. He found also that by varying this percentage¹ (1%) he could also vary the spectrum to either end of the scale--all this over the range of five per cent of ceria. Still further, Welshbach found that other "impurities" would act to produce approximately the same results when mixed with pure thoria.

In his experiments Doctor Kernst found that glowers produced by the mixing of thoria and ceria gave remarkable results, not only as far as their light emitting power was concerned, but as to their higher conductivity². To this mixture he made further additions of other rare oxides, notable among which was the yttria earths, with the result that the conductivity was still further raised. Glowlers were also made with only the two substances, thoria and yttria earth.

1 Bulletin by Welshbach Mantle Company

2 Electrical Review, London, February 24, 1899.

At this point in the development of his lamp, Nernst was faced with the starting difficulty. It must be understood that although these rare oxides are excellent conductors at high temperatures, ordinarily they are classed with the electrolytes, i.e., good insulators at the lower temperatures. To start these latter glowers, an appreciably high temperature was necessary before they became conducting. Doctor Nernst could devise no adequate means to accomplish these high starting temperatures by automatic means.

THE NERNST FILAMENT.

As it may be said of many of the rare oxides¹, zirconia remains almost unaltered in the presence of the oxyhydrogen flame. It has great light giving power and is very refractory, emitting the most intense and fixed light at the higher temperatures. Recognizing these properties and realizing also that, although thoria² was even more valuable for lighting purposes than zirconia because it gives forth a blinding light at the comparatively low temperature of the Bunsen flame, its use as a constituent of his glower was inconsistent with the development of the starting apparatus of the Nernst lamp. He therefore substituted zirconia for thoria and in so doing lowered the starting temperature of the mixture of yttria and thoria.

The object then, of this phase of the work has been to make a resubstitution of thoria for zirconia, and by a proper scheme of percentages of the oxides of thoria and yttria to increase not only the refractiveness but the over-all efficiency of the lamp. If this result could be accomplished, further search might perhaps disclose some feasible means whereby automatic starting could be made commercially possible.

¹ Rare Metals--Chly, p. 140-145

² Richter's Inorganic Chemistry, Smith p 240

CURRENT CONDUCTION THEORY.

A study of the manner in which the conduction of current occurs in the electrolytes, particularly those elements and rare metallic earths in which we are interested, clearly shows a complexity of theory which at once places such discussions upon a very insecure footing. The Ionic Theory of Dissociation, upon which the various theories of current conduction depend, is still a subject for conjecture. We cannot, therefore, place it in the category of exact sciences.

The principle premises¹ upon which Doctor Fernst based his theory of electrolytic action may be taken as follows:

(a) That definite traces of electrolysis are found in some cases; the chemical composition of the cathode after the current has been allowed to pass through the oxide for a long time being found different from that at the anode.

(b) The conductivity of a mixture of oxides was found to be much greater than that for each oxide taken alone.

Doctor Fernst states that the products of electrolysis are continually recombining so the supply of electrolytic ions is maintained constant. The theory of

1 Conductivity of Metallic Oxides, Phil. Mag. Vol. 11

electrolytic dissociation has furnished a simply explanation of conductivity in electrolytes by assuming that the current is carried as a stream of electric charges on the ions into which a certain proportion of the electrolyte is dissociated.

In contradiction to this hypothesis Doctor Horton obtained from experiments upon a number of the oxides such as lime, magnesia, Baryta Plumbic oxide, bismuth trioxide, and a number of others, exactly opposite conclusions which led him to believe the conduction to be mainly metallic in the metallic oxides.

Doctor Horton's arguments were based upon facts, the principle one of which was that if the conduction had been electrolytic some evidence of this action would have manifested itself when the oxides were operated in vacuo.

In direct opposition to this statement it may be shown that the vapor tension resulting from operation of the compounds in vacuum results in a gradual deterioration of that vacuum.

The fact that compounds conduct better than either of their constituents may be explained on the corpuscular theory, i.e., the theory of metallic conduction which makes use of the argument that negatively charged corpuscles are discharged or escape from the ions and

move in an opposite direction to the impressed voltage. There seems to be ample proof that the ease with which a corpuscle may escape depends entirely upon its surroundings. This is clear when we consider that such compounds are mixtures of substances, the one containing many free corpuscles but very little space in which to move (thoria with a high atomic weight), and another (yttria with low atomic weight) in which there is plenty of room but few corpuscles.

Finally, it is known that the number of these charge bearing particles increases with an increase in temperature and that the rate of increase in emission has a direct proportional effect upon the conductivity.

From the statement made, and from many points not cited, there seems to be much conclusive evidence that the conduction of current in electrolytes is mainly metallic, at least, not entirely electrolytic.

Still another theory of current conduction in the case of the Fernst glower depends upon the fact that the air in the neighborhood of a conductor becomes charged or ionized on the passage of a current through the conductor. It therefore seems probable that conduction depends not a little upon this ionized air and that the phenomenon is in the nature of an arc which envelopes the surface of the conductor.

CONSTRUCTION AND OPERATION OF THE WERNST GLOWER.

The Fernst glower in its present form consists of a rod of the material about 25 millimeters long and about 0.63 millimeter diameter. It is formed by forcing through a die a stiff dough of the rare earths mixed with a binder such as gum tragacanth, drying, roasting, cutting into proper lengths, and finally attaching lead wires. These operations are performed with no little difficulty, particularly the last one--that of attaching the lead wires. Doctor Fernst made his terminals by making a few turns of fine stranded platinum wire about the end of the staff, afterward applying a paste of the same material. A serious difficulty was encountered in this form of terminal. After the glower had been in operation a short time there was found to be a loosening of the spiral due to shrinkage in the staff. Later developments by Marshall Hanks brought out a terminal making use of this shrinking action. By heating the end of the staff to a molten state he embedded a small bead of platinum in the very ends, to which, after cooling, the lead wires could be attached. It is clear that shrinkage in the staff will only tighten the platinum bead in its socket.

The characteristics of the glower with reference to voltage and current have given rise to the use of a

steadying resistance, or ballast. As the current in the glower is increased, the voltage across the terminals rises, at first rapidly, and then more slowly to a maximum, beyond which it again drops off with increasing rapidity as the current and resulting temperature increase. Beyond the point of maximum voltage the resistance of the glower drops off so rapidly as to make the current difficult to control. A very slow rate of vaporization results from operation, this rate increasing with the efficiency at which the glower is operated.

Although the efficiency of the present glower is nearly twice that of the average carbon lamp, and in the larger sizes of Pernst lamps has a better efficiency than the newer tungsten lamps of equal candle power, there are certain points which suggest a possibility of betterment.

It is known that up to a certain point the efficiency of a glower increases with the temperature, but, due to the fact that they sag and become plastic at high temperatures, it is not commercially possible to operate them at these high temperatures. Hence, with their present composition, the efficiency of the glowers is limited by certain features, the most objectionable among which is vaporization.

The work to be taken up in this section is then, to

ascertain whether substitution of thoria, with its higher rate of light emission at lower temperature, will not effect the proper results.

EXPERIMENTATION AND RESULTS.

The method of preparation of thoria for these experiments will be described in the following paragraph. The method used was the same for all the work and will not again be mentioned.

Twenty grams of thorium chlorate (ThCl_4) was dissolved in about three-quarters of a liter of clean water. A precipitate of thorium oxalate was produced by slowly adding, in excess, a hot solution of oxalic acid, stirring briskly during the formation of the precipitate. The precipitate thus formed was filtered and washed clean with several washings of hot water until the run-off showed neutral on turmeric paper.

The clean precipitate, together with the filter paper, was placed in a drying oven to remain over night. From here the thorium oxalate was ignited in a platinum crucible, at first slowly to a red heat and at red heat for two or three hours. The oxide thus formed (ThO_2) was very white and chalky:

The first mixture to be tried was 90 per cent thoria and 10 per cent yttria. Five grams of this mixture was carefully weighed, to which was added five per cent of gum tragacanth, and the whole kneaded thoroughly by adding a few drops of distilled water. The final form of the mass was a stiff but pliable putty.

The mixture was now placed in the press and forced through a die the exact size of a $\frac{1}{60}$ drill (0.04") in diameter. A long thread was formed in this manner and allowed to dry thoroughly before baking.

The baking process was carried on by first cutting the gut into convenient lengths and passing these lengths slowly back and forth through the oxy-gas flame. Three or four passes were considered sufficient to burn out the gum tragacanth. It was found that too much burning served to crumble the filaments or induce fractures. Great care was necessary to heat gradually. Filament lengths of about three-quarters of an inch were now made and stranded platinum wire (6 wires $\frac{1}{50}$ twisted) was wound twice around each end with a lead length of one and one-quarter inches. These end connections were shaped around a wire about the size of a filament and then forced gently over the ends of the staff to avoid failure by breakage. A paste for the end beads was prepared of such a constituency that it settled into the corrugations of the wire, making a secure joint. The paste was made as follows: All old ends and broken pieces of filament were ground to a fine powder in a mortar. To this powder was added a little more yttria for constituency, the whole being brought to a pasty form by adding a very little pure water. A very small

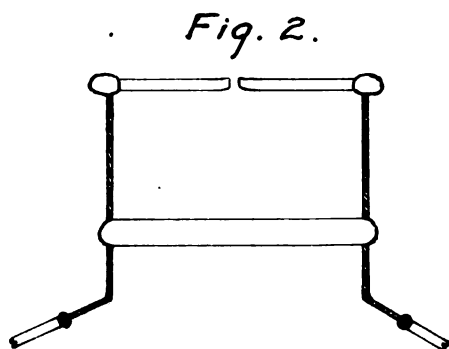
amount of thorium nitrate was added because of the adhesive qualities which it imparts to a mixture.

After drying, these beaded ends were baked in the same manner as the filaments themselves. Serious trouble was encountered in that the mixture in the bead seemed to scale off and blister in the flame. This was perhaps due to insufficient time given for baking. Small glass rods were welded to the platinum ends about three-quarters of an inch from and parallel to the glower so as to afford easier and safe handling. Finally, the leads were lengthened by welding short lengths of #16 copper wire to them.

TESTING.

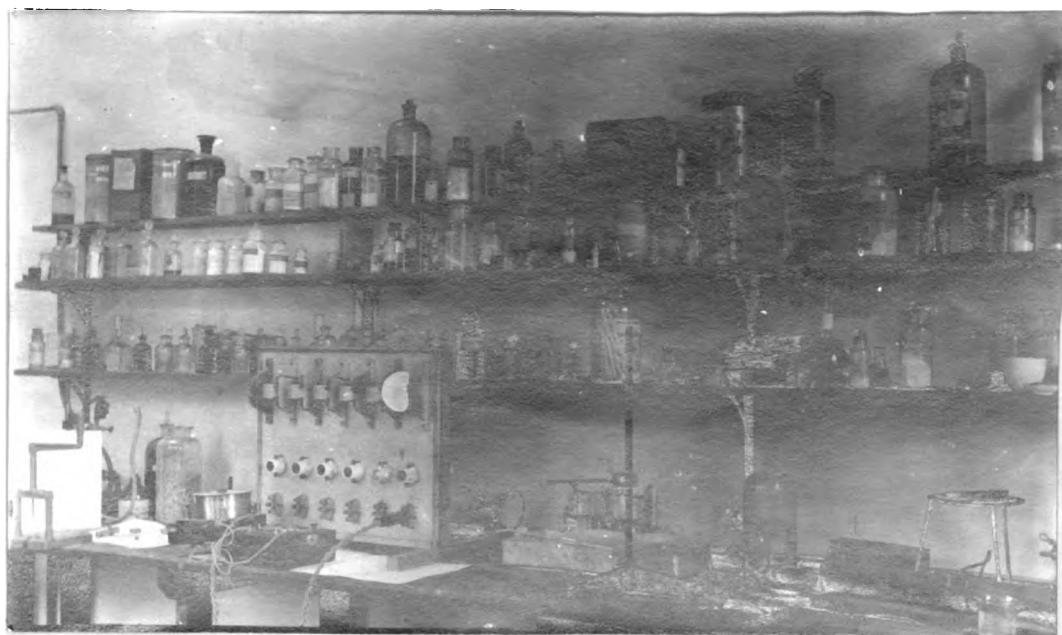
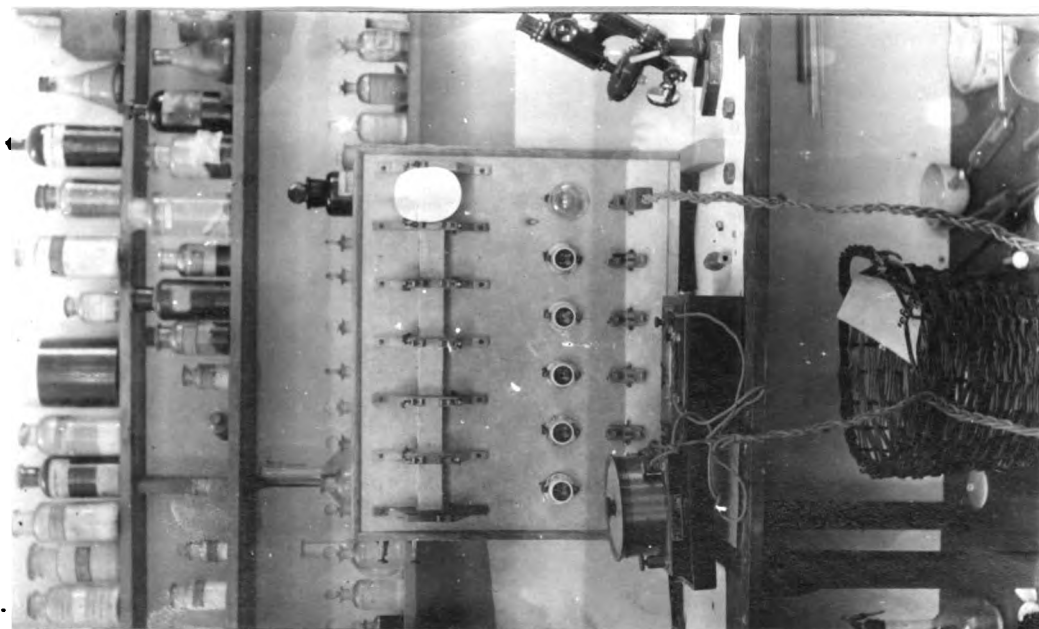
A test was attempted on each glower constructed, some defect being developed in each one. No data was obtained because of so much variation, due perhaps to poor end beads. Another fact was made evident--nearly every filament contracted some defect. Some became loose in the end connections, a small arcing effect being produced which finally destroyed the platinum wire. A peculiar thing was made evident. All filaments that continued to glow for any length of time developed a sectional crack midway between the ends as shown in

Figure 2.



To facilitate the testing of a number of glowers at one time, a test board was constructed whereby six glowers might be run at once. Special arrangements of circuits were made so that current and voltage values might be obtained without interrupting the circuit of any single glower. This allowed the use of but one set of instruments. A photograph of the complete board with instrument plug is shown on the next page.

Several batches of the ninety and ten per cent mix-



ture were made up precisely as before. The terminal paste in some of these batches was varied in an effort to obtain a more lasting terminal. In some the thorium nitrate was left out and this seemed to give better results. The tests on all of these glowers gave no results.

No little trouble was encountered in starting these glowers. With a large plain resistance or lamp ballast the glowers would not start in the hot flame of the oxygen flame. Now this we do not attempt to explain because there is no drop across the resistance until current begins to flow. The glowers were started by cutting that resistance down to a low value. However, the ballast could not be cut in again fast enough to avoid the rush of current, which either burned off the terminal leads or else fractured the filament. In all cases, the fractured glower was found to be tubular, i.e., the center had been melted out, and in some cases the molten matter could be seen to shoot from miniature volcanoes on the surface.

This melting out of the center can be explained by the fact that in any conductor whose conductivity is low, the flow of current tends to be axial. Therefore the center of the conductor may be in a molten state while the outside is intact.

In the construction of glowers great care and some

dexterity is necessary because of the fragility of the staff before it has been in operation. It is a peculiarity of filaments that, after being in operation some little time, they become extremely hard and are very durable.

At this point in the work a change was made in the percentages of thoria and yttria in the hope of obtaining results. The thoria constituent was raised to 95 per cent and the yttria lowered to 5 per cent.

A great deal of time was spent in an effort to start these glowers. They were tried on the 500 volt direct current city circuit, but without success. Finally a transformer was obtained and 1100 volts alternating current applied at the terminals in connection with a suitable lamp ballast. Only a few were successfully flashed, the higher voltage strain seemed to fracture the staff just beyond the terminal bead. We thought that if they could be successfully flashed no trouble would be encountered in starting at a lower voltage. This was not true because the flashed glower required the same voltage to start as before.

In the first few batches of 95 and 5 per cent glowers the same method was employed in making the paste, but in the last few batches a change was made by adding about five per cent of zirconium chlorate. Appli-

cation was made by putting on a thin layer of paste, roasting and applying another layer until a bead of sufficient size had been built up.

Filaments one inch long refused to start on 220 volts alternating current, and to simplify apparatus the glower length was cut down to five-eighths of an inch. Glowlers of this length could be started on 220 volts, but only in the intense oxy-gas flame.

Tests were made upon these latter glowers, but with no immediate results. However, a small amount of data was obtained from one glower. The values given cannot be relied upon as representative because almost immediately after starting a defect developed in one terminal which caused an arcing action. The data is given only to show the current and voltage relations.

Time of start	3:13 P.M.
Length between terminals	9/16 inch
Diameter	0.028 inch

Number of Reading	Time	Amperes	Volts x K
1	3:13	0.17	159
2	3:22	.16	158
3	3:27	.16	157
4	3:32	.155	159
5	3:40	.160	156
6	3:42	.195	156
7	3:51	.20	154
8	3:57	.21	163
9	4:06	.18	162
10	4:50	0	0

At reading #5 the ballast was decreased, increasing the current intake at the glower. At this time the glower seemed to be burning at an excellent efficiency, that is at a very white heat.

A single glower Fernst lamp was set up very near the above glower and a white porcelain background provided for the test glower so as to make the conditions more favorable for comparison. The greater brilliancy of the test glower was then particularly noticeable.

This glower was operated on 500 volt direct current circuit. The original was a straight rod, but after being in operation a short time there developed a bend which had its peak near the positive terminal, with a gradual

slope toward its negative end.

In conversation with Mr. Hanks, a former Fernst lamp worker, it developed that the phenomenon is true to a more or less extent for all glowers burned upon direct current circuits. A particularly noticeable feature of operation on direct current circuits was the difference in brilliancy at the positive end over that of the negative end. In fact, the negative terminal was decidedly cool. Again, this phenomenon is noticeable in Fernst glowers and is the cause of terminal troubles in the case of lamps used on direct current circuits.

In conclusion, it is difficult to make a statement as to the results obtained. This is due, for the most part, to a non-uniformity of operation of glowers of precisely the same construction throughout.

In most cases of construction, non-uniformity is usually placed at the door of the differing grades of material. Particularly is this true in the case of the Fernst glower of its yttria content. The yttrium earths are a composite mass of a number of earths such as yttrium, yttrium, and some others. Variations in the percentage of constituents results in variations of atomic weight of yttrium earth, and in the case of the Fernst glower, as spoken of before, seems to be the cause of variation in lamp hours between one glower and another. The yttria

used in these experiments was taken from one source only.

As to the thoria content there may be some cause for question on account of its being produced in the laboratory. However, as in the case of the yttria, the thorium chlorate from which thoria was produced came from the same bottle (marked Schuchardt's Thoritum Chlorate) for all the glowers.

The manner of making the terminals is a point in question. Due to the changes made and the manner of applying the paste, coupled with the adverse results obtained, it seems probable that the discarding of this terminal for some other which will withstand the extreme temperature would obtain for results.

Again, if the roasting of glowers seems an important factor in the making, it would probably be expedient to arrange an electric furnace where uniform heating could be accomplished. There seems reason to believe that with the oxy-gas flame used in this work there were miniature cracks produced all over the glower surface by the curling and uncurling of the gut in the flame.

It seems, therefore, that further work will be necessary before a positive statement can be made as to the use of a glower made of a mixture of thoria and yttria, to obtain thereby a higher efficiency.

THE OPERATION OF NITRIDE CLOWERS IN NITROGEN.

THE POSSIBILITIES OF THE NITRIDES.

Since the nitrides of various rare elements such as cerium, titanium, vanadium, and boron have been found to be very refractory in character, and since some of these are conductors of electricity even when cold, it was thought that it might be possible to form high efficiency incandescent lamp filaments from them.

Cerium, among others, was known to have the remarkable property of uniting with pure nitrogen when at a red heat, forming the nitride of cerium. The reaction is exothermic, and the amount of heat generated is so great that the mass undergoing reaction glows with a brilliancy equal to that produced by the carbon arc. The compound is stable at excessively high temperatures, and is fusible with difficulty. The nitride is also stable at low temperatures so long as it is kept out of contact with water vapor, and is a good electrical conductor. For these reasons cerium nitride was considered a promising material upon which to conduct experiments looking toward an improved high efficiency lamp.

The element cerium from which the nitride is made is, as yet, not a commercial product. However, experiments carried on at the present time at the University of Wis-

consin by Mr. Alcon Hersch (1911)¹ on the isolation of metallic cerium have lead to favorable results and to the belief that this heretofore rare element can be made a commercial product. In view of this fact, and the fact that nitrogen can be made in a comparatively easy manner, great commercial possibilities may be expected of cerium nitride as a substitute for carbon as the incandescent element if it is found to possess the requisite stability under the conditions proposed.

Should enough cerium be available, the writers proposed to test out the efficiency and life of the cerium nitride filaments, both in vacuum and with the lamp bulb filled with nitrogen gas. However, tests made under the latter conditions are the primary object of this part of the work. As far as the writers have been able to determine, practically no data or other material is available on this subject. However, Mr. Whitney of the General Electric Company has made and operated cerium nitride filaments in vacuum.

The idea of operating such filaments in an atmos-

1 NOTE. Mr. Hersch has succeeded in isolating about 1000 grams of pure cerium. The authors of this thesis are indebted to him for the cerium used in the attempt to make cerium nitride.

phere of nitrogen is, that under such conditions, the filaments will not be attacked chemically and that under the increased pressure of an inert gas a higher operating temperature may be possible, not only to compensate for the added heat convection and conduction losses, but that the net consumption of watts per candle power will be less than for the present high efficiency lamps.

METHOD OF MAKING NITROGEN.

Before cerium nitride could be made, it was first necessary to produce some nitrogen. There are a number of methods by which this element may be isolated, but the one used, that of passing air over red hot copper inclosed in an iron tube, seemed the most simple and efficient with the apparatus available.

The apparatus consisted of a standard two inch wrought iron pipe inclosing a roll of copper gauze and heated by passing an electric current through a nichrome ribbon wound about it and insulated from it by asbestos paper. Excessive radiation of heat was prevented by packing asbestos fiber about the pipe, which was held in place by suitable brick walls. The brick walls served also to contain the asbestos fiber packing. Four aspirator bottles were connected to the furnace. The apparatus described above is represented in Figure 3.

An attempt to make nitrogen was made in the following way. After turning on the current so as to heat the furnace, the joint F was opened and the bottle F raised in order to allow G to fill with water, thus driving out all the air contained in it. E was then lowered to allow the water from D to flow into E and fill up with air from the atmosphere. The joint F was then closed. It will

be seen that the apparatus contains air entrapped in the bottle D and in the furnace A. The stopcock B was now opened as shown in the figure, thus affording a passage of the air in D to the bottle G through the tube C and E and through the furnace containing the copper A. By raising E and lowering F a pressure was created on the air in D, forcing it to flow over the hot copper in A into the bottle G. Now by reversing the relative positions of E and F the air will be forced from G back into D. Again reversing the relative positions of the bottles E and F the air is forced back into G. In this way the gas contained within the apparatus was made to pass over the hot copper a number of times so as to remove all traces of oxygen. Owing to a small leak in the furnace which we were not able to stop care was taken to keep the pressure within the bottles and furnace slightly above the atmospheric pressure in order to allow no external air to leak in.

A number of attempts were made to remove all traces of oxygen from the air enclosed in the aspirator bottles, but for some unknown reason these attempts were unavailing. The air was passed through the electric furnace as many as twenty-two times, the copper being regenerated twice during this time by passing hydrogen over it while hot. Tests made by placing a sample of the gas in inti-

mate contact with pyrogalllic acid showed a presence of three per cent of oxygen.

METHOD OF MAKING CERIUM NITRIDE.

The apparatus set up for the purpose of making cerium nitride is also shown in Figure 3. It consisted of a hard glass combustion tube L containing an iron boat V upon which was placed the cerium. One end of this tube was connected to the air pump by means of glass and rubber pressure tubing. The other end was connected to a glass bulb J fitted with a ground glass stopper and two stopcocks K and I. The other end of this bulb was connected to the furnace by means of a double opening stopcock B. Phosphorus pentoxide was placed in the bulb J for the purpose of removing any traces of moisture that the gas might contain on coming from the aspirator containing bottles. All joints were made with joint grease in order to make them air tight.

The first attempt to make cerium nitride resulted negatively due to the presence of a small amount of oxygen in the nitrogen. A small amount of cerium was placed on the iron boat V within the combustion tube L. The line of tubing from the air pump up to the furnace was exhausted for some time by means of the oil vacuum pump. A small amount of the nitrogen was then admitted and the whole again evacuated. This process was repeated a number of times in order to scavenge out the last traces of air if possible. Enough nitrogen was then admitted to the

combustion chamber to completely fill it at a pressure about that of the outside atmosphere. The tube was then heated by means of Bunsen burners until the iron boat became a deep cherry red. The reaction expected did not occur. In fact, no apparent change took place. The compound formed became red which, without doubt, was due to the heat externally applied and not due to an exothermic chemical reaction. On removing the compound thus formed and bringing it in contact with water no noticeable reaction took place, thus proving that it was not cerium nitride, but some other compound of that element.

Further attempts were made to remove the last traces of oxygen from the supposedly pure nitrogen gas by regenerating the copper and passing and repassing the gas through the furnace. It was at this point that the pyrogallie acid tests for oxygen were made showing the presence of three per cent of oxygen.

A second attempt to make cerium nitride resulted favorably. The nitrogen remaining from the previous attempt was bubbled through pyrogallie acid in order to remove the remaining oxygen. The apparatus used consisted of five aspirator bottles connected up as shown in Figure 4. The pyrogallie acid was placed in the bottle C and the nitrogen gas in bottle B. E was first raised above the level of D in order that the latter might fill with water from

E and thus drive out all air in it. The tube H connecting aspirator bottles B and D being pinched shut with a pinch cock, the gas in B was forced to bubble through the acid in C by raising the bottle A. This created a pressure above the acid in C great enough to force the gas through G, replacing the water in D. The gas in D was then by-passed through H back into B from where it was again bubbled through the pyrogalllic acid as before. In this was the last traces of oxygen were removed. The bottle D containing the nitrogen gas was then connected to the cerium nitride apparatus at the point I in Figure 5, and another sample of cerium was placed upon the boat K. This time the air in the combustion chamber L was removed by a mercury vacuum pump shown diagrammatically in Figure 5. The cock K was then closed and I opened, thus allowing J to fill with nitrogen and remain for a short time in intimate contact with the phosphorus pentoxide. The cock K was again opened to allow the dry gas to pass into L. This process was repeated until L was filled with nitrogen at a pressure slightly greater than atmospheric pressure. The iron boat with its sample of cerium was then heated externally by a Bunsen burner and an oxy-gas flame. No reaction was noticed as the cerium gradually became heated until the iron boat became dull red in color. At this point a slight increase in temperature, due undoubtedly to the exothermic reaction,

was indicated by a few spots in the boat becoming suddenly bright red in color, but as suddenly dying out again. The boat and its contents were maintained at a bright red heat for ten minutes.

On taking the boat from the furnace after cooling over night, two distinct compounds were present upon it, both giving off an odor of ammonia. One compound was lustrous bronze black in color, while the other, a small portion of the whole, was bright yellow in color. The former compound, when heated in a test tube with potassium hydroxide, gave off a very distinct odor of ammonia. Red litmus paper was turned to blue thus indicating cerium nitride. The latter compound gave no such reaction, which proved that it was not cerium nitride, but another compound of that element.

The cerium nitride thus produced was ground up, mixed with a small amount of paraffine wax, and squirted into small pencils. The pencils, after remaining in air for twenty-four hours, became fairly hard and brittle, and cracked open their full length, thus making it impossible to test them.

Appratus For Making Nitrogen And Cerium Nitride

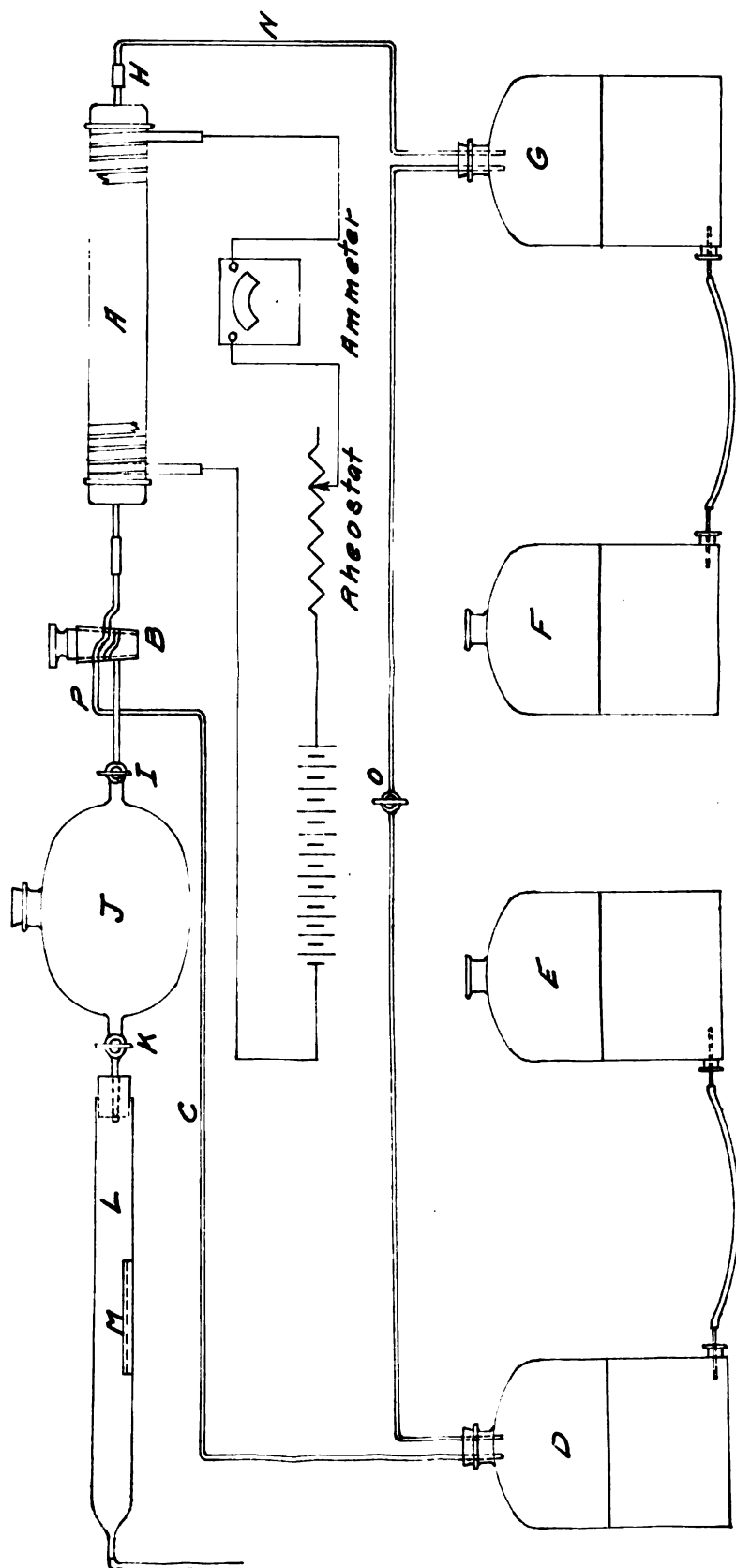


Figure III

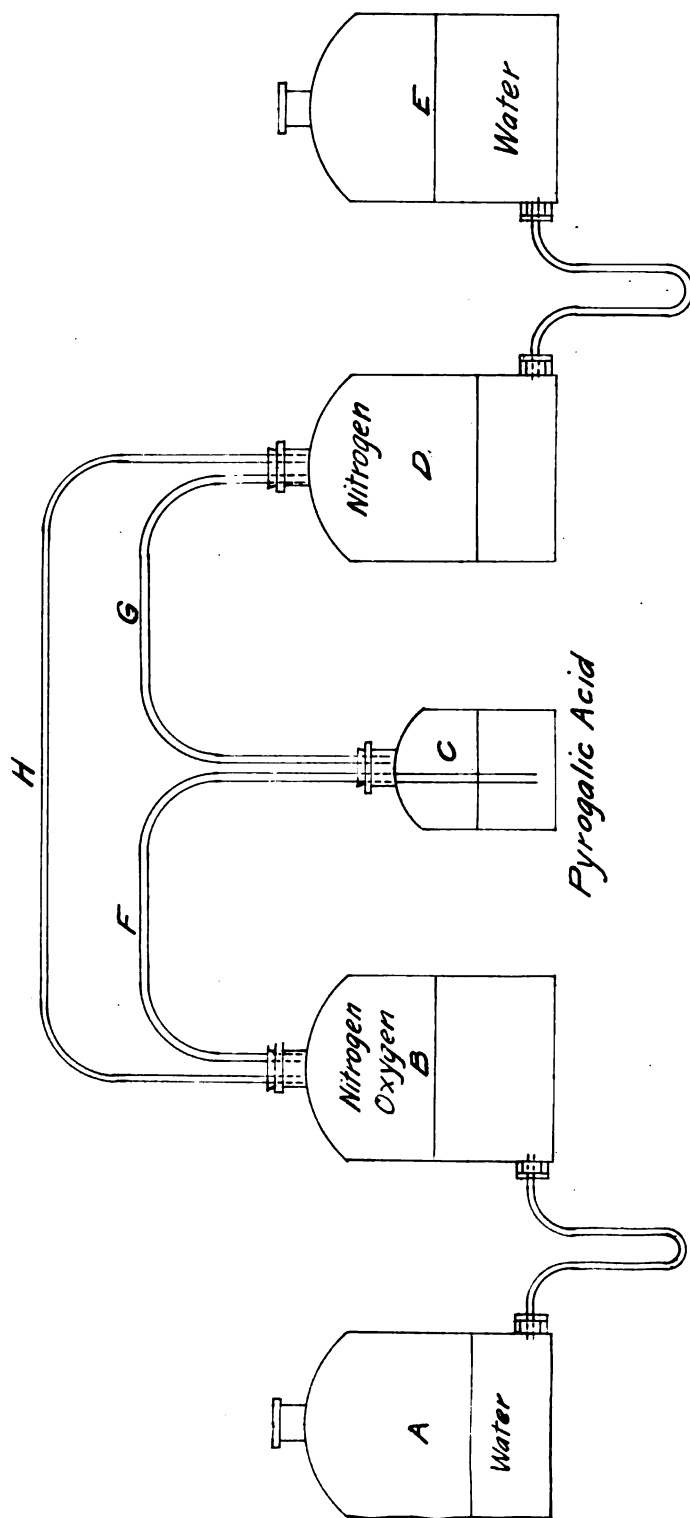


Figure IV

*Apparatus For Making
Cerium Nitride*

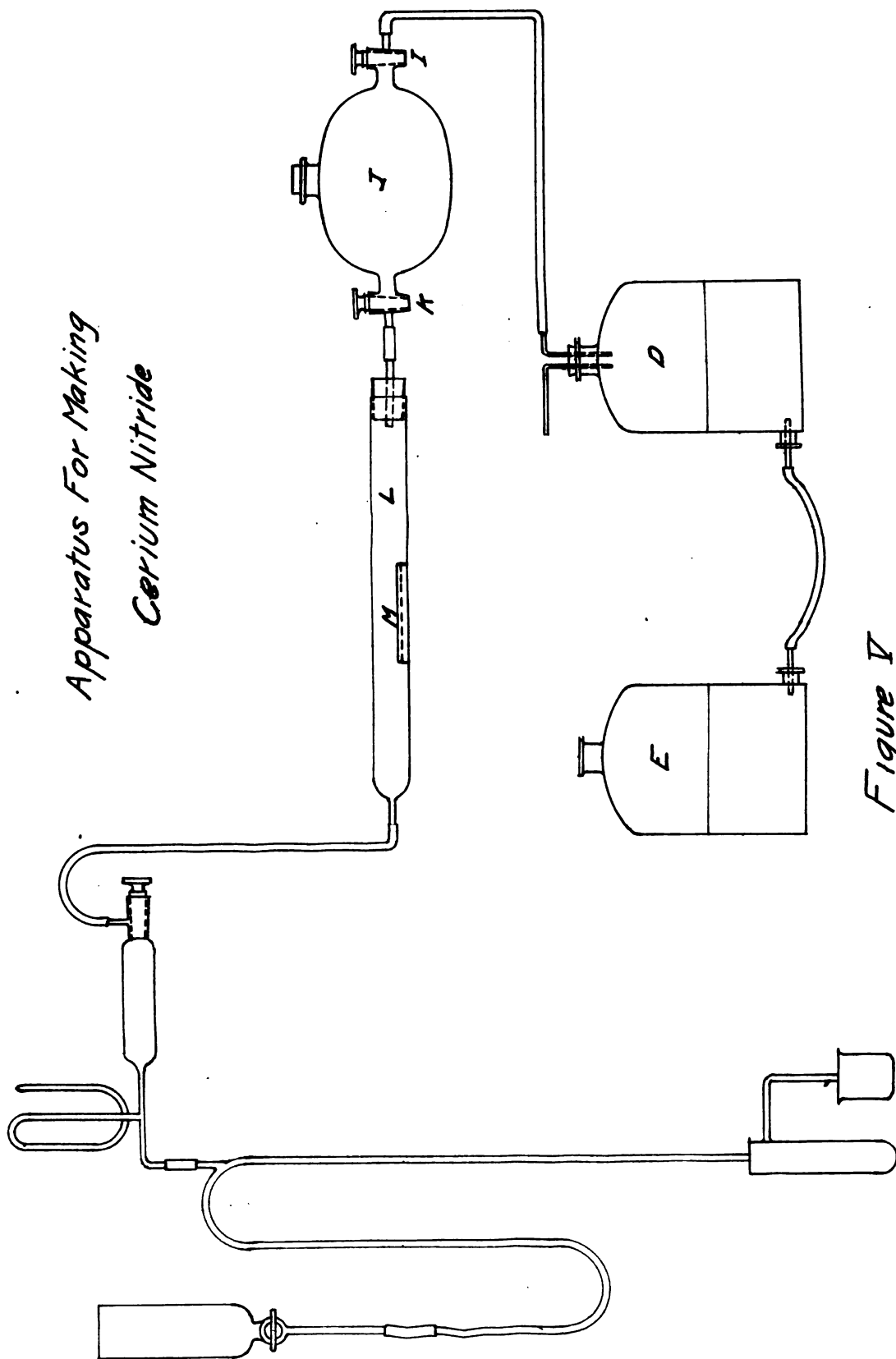


Figure V

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Beside the work upon which Mr. Glover reports in this thesis, relating to the operation of carbon filaments in carbon containing gases, he gave material assistance to Mr. Kartak and Mr. Lent in their study of the effect of argon upon the life operation of a carbon incandescent lamp.

M. C. Beebe.

Approved

..... *M. L. Beebe*

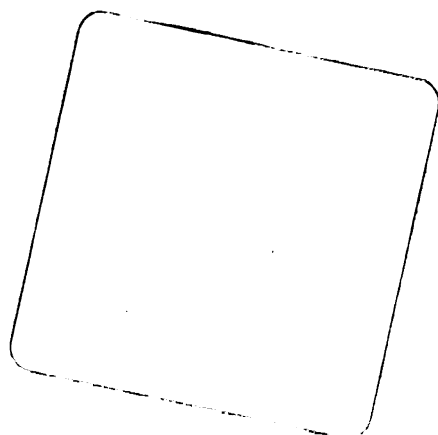
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